Miscellaneous Paper SL-94-1
April 1994

US Army Corps
of Engineers
Waterways Experiment
Station

Efflorescence Study, Fort Leonard Wood, Missouri

by Tony B. Husbands

Prepared for U.S. Army Engineer Division, Missouri River
U.S. Army Engineer District, Kansas City
U.S. Army Engineer Waterways Experiment Station

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Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Engineer Division, Missouri River
Omaha, NE 68101-0103

U.S. Army Engineer District, Kansas City
Kansas City, MO 64106-2896

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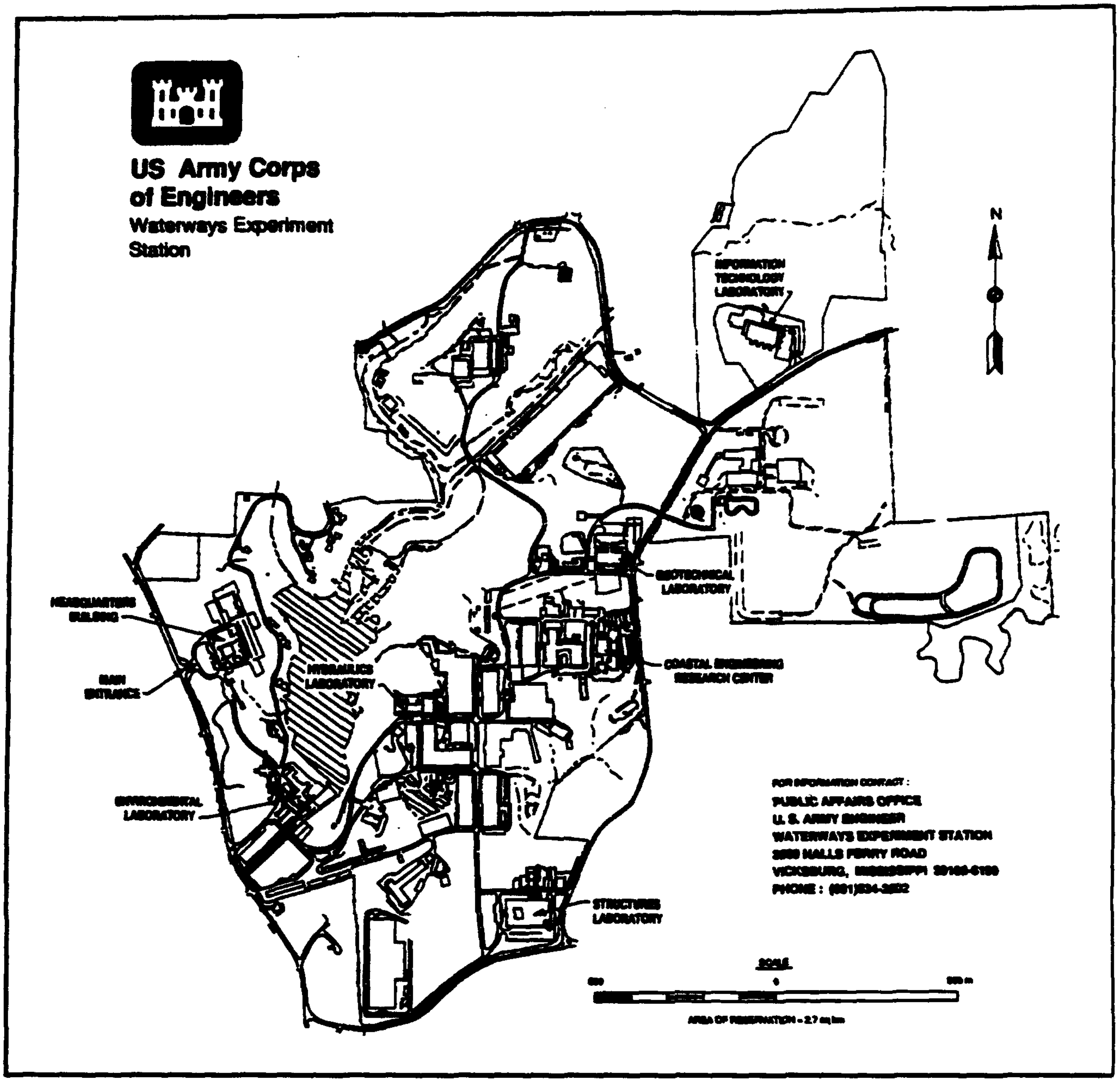

Waterways Experiment Station Cataloging-in-Publication Data

Husbands, Tony B.
Efflorescence study : Fort Leonard Wood, Missouri / by Tony B. Husbands ; prepared for U.S. Army Engineer Division, Missouri River, U.S. Army Engineer District, Kansas City, and Concrete Technology Information Analysis Center, U.S. Army Engineer Waterways Experiment Station.
41 p. : ill. ; 28 cm. -- (Miscellaneous paper ; SL-94-1) Includes bibliographic references.
1. Efflorescence. 2. Exterior walls -- Missouri -- Fort Leonard Wood -- Maintenance and repair. 3. Dampness in buildings. I. United States. Army. Corps of Engineer. Missouri River Division. II. United States. Army. Corps of Engineer. Kansas City District. III. U.S. Army Engineer Waterways Experiment Station. Concrete Technology Information Analysis Center. IV. Title. V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; SL-94-1.
TA7 W34m no.SL-94-1

Contents

Preface

The study reported herein was conducted for the U.S. Army Engineer Division, Missouri River, and the U.S. Army Engineer District, Kansas City, as requested by Headquarters, U.S. Army Corps of Engineers (HQUSACE), by the Concrete Technology Division (CTD), Structures Laboratory (SL), U.S. Army Engineer Waterways Experiment Station (WES). The funds for publication of this report were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC Report No. 91.

The study was conducted at WES during the period of March 1993 to September 1993 under the direction of Messrs. Bryant Mather, Director, SL, Kenneth L. Saucier and Dr. Tony Liu, former and present Chiefs, respectively, CTD; and Dr. William N. Brabston, Chief, Engineering Sciences Branch, CTD.

The cooperation of Mr. Ervell Staab, U.S. Army Engineer Division, Missouri River, and Mr. Larry Irvin, Fort Leonard Wood, Missouri, is greatly appreciated.

At the time of preparation of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
gallons (US liquid)	3.785412	litres
inches	25.4	millimetres
pounds (force) per square inch	0.06894757	megapascals
square feet per gallon	0.024542	square metres per litre

1 Introduction

During the winter of 1992-93, some of the brick buildings at Fort Leonard Wood, Missouri, developed excessive efflorescence. The efflorescence appeared as a white deposit on the face of the walls. Months prior to the noticeable deposits of efflorescence on the buildings there was a prolonged cool rainy period with a much higher than average amount of precipitation. These are ideal conditions for subsequent production of efflorescence, since there is a slower rate of evaporation and a continuous dampness in the wall.

An inspection of the buildings was made in December 1992 by personnel from the U.S. Army Engineer Division, Missouri River (MRD), and the U.S. Army Engineer District, Kansas City (KCD). Three buildings were specifically identified as having excessive efflorescence: the Commissary, the Davis Recreation Center, and the Engineer School Library. The Commissary and Engineer School Library were fairly new buildings having been completed within the past few years, while the Davis Recreation Center was about 8 years old. The inspection revealed well capped walls with good detailing and installed flashing. The brickwork and joints indicated good workmanship. There was some evidence of cracking ("debonding") between the mortar and the brick immediately above the mortar joint. The exact method of water entering into the walls was not established, but the debonded mortar joints would contribute to moisture penetration into the walls. A sample of the masonry mortar and a brick containing a thin coating of efflorescence were taken from the southside (rear) of the Commissary building and sent to the Missouri River Division Laboratory for analysis. A petrographic examination indicated that the efflorescence was predominantly calcium carbonate and that the source for the efflorescence was the mortar and not the brick.

The U.S. Army Engineer Waterways Experiment Station (WES) was asked to assist in the investigation of the efflorescence problem at Fort Leonard Wood. An inspection of the buildings at Fort Leonard Wood was made by WES personnel on 26 Jan 93. Personnel from the MRD, KCD, and Headquarters, U.S. Army Corps of Engineers (HQUSACE), were also present for the inspection. A Research Proposal (Appendix A) was prepared by WES, and this study was started in February 1993. A survey was made through a literature search, and by contacting consultants and professional organizations, to determine what could be done to eliminate or reduce efflorescence in existing structures and what could be done to construction specifications or practices to prevent/reduce efflorescence in new construction.

The Commissary building at Fort Leonard Wood was selected as the site for field testing which included: (1) tuckpointing of mortar joints, (2) application of surface sealers, and (3) water penetration tests.

2 Inspection of Buildings

The author, Messrs. Ervell Staab, MRD, Fred Kraft, KCD, and Charlie Gutberlet, HQUSACE, inspected the buildings at Fort Leonard Wood on 26 January 1993. Personnel from MRD and KCD had previously inspected the buildings in December 1993. A report (Staab 1993) was prepared by MRD, which described the condition of the buildings, presented the MRD Laboratory test results, described constructions materials, suggested possible causes, and made recommendations.

Efflorescence on the Commissary can be seen in Figures 1 and 2 and on the Engineer School Library in Figure 3. Efflorescence was visible over almost all of the south (rear) and east sides of the Commissary building. Some efflorescence was also visible on the west side. The Davis Recreation Center had some efflorescence located primarily on the south and east sides. The Library wing of the Engineer School had noticeable efflorescence on the south end of the building. The Headquarters and academic wings of the Engineer School were generally free of efflorescence. Other buildings inspected included the Unaccompanied Officers Quarters, which was constructed about the same time as the Engineer School, and some on-going new construction. Very little efflorescence was noted on the Officers Quarters.

A brick that contained efflorescence on the surface and the surrounding mortar was removed from the south wall of the Commissary building for analysis at the MRD Laboratory. A petrographic examination indicated that the efflorescence (salts scraped from the face of the brick) was predominantly calcium carbonate. Potential sources of soluble calcium salts were not found in the brick matrix. The examination showed that the masonry mortar was the source for the efflorescence and not the clay brick.

The three buildings were inspected in considerable detail for causes of efflorescence problems during the first inspection. The MRD report (Staab 1993) stated that the inspection revealed consistently good detailing of the buildings to prevent common water related masonry problems such as uncapped walls and discontinuous flashings. The brickwork and joints showed good workmanship. The roof of the Commissary was closely inspected and it showed excellent detailing and construction along the eave and parapets. There were no obvious engineering or construction flaws evident from their visual inspection. The report noted that there was some evidence of cracking ("debonding") between the mortar joints and the brick immediately above the

mortar joint. Random cracks between the brick and mortar were tested for water penetration using a RILEM tube. Some of the cracks took on large amounts of water whereas others did not, which indicated that some of the joints were completely debonded. It did appear that large amounts of water could enter the wall in this manner. WES observed some of the testing with the RILEM tubes during the second inspection.

The only potential problem identified after inspecting the buildings was the debonding of the masonry mortar from the brick. Some of the consultants contacted stated that this was more common with higher-strength mortars. An evaluation of the submittals indicated that a high-strength mortar was used for the Commissary building. Strengths at 28 days varied from 4,150 to 5,125 psi. These test results were in excess of what was expected for a Type S mortar which is less than 3,000 psi based on the proportions specified. ASTM C 270 specifications for masonry mortar (ASTM 1992a) requires that a Type S and Type M have minimum compressive strengths of 1,800 and 2,500 psi, respectively. It was concluded that the excessive mortar strength was generally the result of the contractor having used a Type S mortar proportioned to clearly exceed the minimum strength requirements. The mortar test submittals for the Library wing of the Engineer School were not available. Mortar tests for the Academic wing of the Engineer School showed strengths of about 1,200 psi at 28 days, which indicates that a Type N mortar was probably used. The Unaccompanied Officers Quarters constructed at approximately the same time as the Engineer School specified a mortar proportion of 1 part cement, 1/2 part lime, and 4 1/2 parts aggregate, which would be a Type S as specified by ASTM C 270 (ASTM 1992a). The mortar strengths for this building were 2,700 psi. The Academic wing of the Engineer School and the Unaccompanied Officers Quarters both were essentially free of efflorescence. Based on these findings, it was concluded that the efflorescence was contributed to the debonded mortar joints which allowed large amounts of water to enter into the walls.

3 Field Tests

Field tests were arranged through the Corps of Engineers Area Office at Fort Leonard Wood. The southwest wall of the Commissary building, as shown in Figure 4, was selected as the site for the field tests. Before field tests were started, the search for remedial methods to prevent efflorescence from recurring was started and information obtained from this search was used in establishing what field tests would be performed onsite. Methods for measuring water penetration into the walls and methods to slow down or stop water penetration into the walls were sought. Field work performed included: water-penetration tests, tuckpointing of joints, and the application of a surface sealer.

Water-Penetration Test Methods

Two test methods were selected for measuring water penetration the RILEM test and a method developed by the Construction Technology Laboratory (CTL). The RILEM test consists of the use of a graduated plastic cylinder that is mounted to a wall or test specimen by means of a putty. The apparatus is filled with water and the quantity of water entering the material during a specified period of time is read directly from the graduated tube. A RILEM tube with dimensions is shown in Figure 5. CTL's test apparatus consists of a 2-in.-diam chamber, which is attached to a wall. Two anchors were placed in a bed joint and two clamps were attached to the wall to firmly support the chamber against the wall. Putty was placed in front of a rubber gasket that sets around the chamber (Figure 6). Water was then pumped to the chamber until the chamber was filled as indicated by an overflow valve. Water was then forced into the wall under pressures ranging from 5 to 15 ps; 5 psi was selected for these tests. The amount of water penetration was then measured by a flow meter. A test in progress is shown in Figure 7.

CTL was contracted to perform the water-penetration test using its equipment. The first test was made on 11 May 93, the same week that the tuckpointing and sealer were applied. Three locations on the brick panel that were to be coated with the sealer were tested before the sealer was applied. The tuckpointing had been completed one day prior to the testing, therefore, this section of the brick wall was not tested because the masonry mortar had only cured for 1 day.

The RILEM tests were made by WES on the last visit to Fort Leonard Wood. Three RILEM tubes were attached to three different locations on the wall with putty. They were then filled with water with a 1-min delay between filling of each tube. The quantity of water entering the wall was read from the graduated cylinders every 5 min up to 20 min for some of the locations tested. Three areas of the wall were tested with the RILEM tubes: the section of the wall that was coated with the sealer, the section of the wall that was tuckpointed, and an untreated section of the wall which was located in the wall panel next to the wall section that was sealed.

Tuckpointing of Mortar Joints

The Corps of Engineers Area Office, Fort Leonard Wood, arranged with a local contractor to do the tuckpointing for WES. The contractor reviewed the specifications for the Commissary building and selected a mortar mixture similar to the one used during construction. It contained 1 part portland cement, 1/2 parts lime, and 4-1/2 parts sand. The type of colorant that was used in the original mortar was obtained, and trial batches were made to obtain a color that would closely match the original mortar. The contractor added a small amount of an acrylic latex to the mortar mixture. The contractor failed to let the mortar set for 1 to 2 hours after the addition of mixing water as recommended by many of the documents reviewed by WES (Panarese, Kosmatka, and Randall 1991; Beall 1993). WES did not specify the method of mixing or placement in the purchase order.

The tuckpointing was done on 10 May 93 on a section of the wall that was located approximately 3 ft to the right of the third downspout from the southwest corner of the building. The area tuckpointed was 6 ft high and 10 ft long. A 4-in.-diam diamond blade attached to a sidegrinder was used to cut out the old mortar to a depth of 1/2 to 3/4 in. A small chipping hammer was used to remove some of the mortar in the head joints that could not be removed with the saw. Saw cutting of the mortar joints is shown in Figure 8. The joints were then cleaned using a stiff brush and water. The contractor placed the new mortar into the prepared joints that afternoon. The contractor did state that the mortar was slightly on the wet side, because of rain that day which soaked the sand used in making the masonry mortar.

Upon removing the old mortar it was discovered that many of the head joints were not full of mortar. Some of the unfilled mortar joints are shown in Figure 9. Unfilled mortar joints would also contribute to excessive water entering into the walls. Unfilled mortar joints could be attributed to poor workmanship in that the contractor possibly did not butter both edges of the brick before setting them in place.

Application of Surface Sealer

WES is presently testing many sealers for masonry surfaces under the Repair, Evaluation, Maintenance, and Rehabilitation Research Program (REMR). Manufacturers of some of the sealers under test and other manufacturers were contacted by WES to find sealers that would retard entry of water into narrow openings in masonry such as debonded joints. Only two of the manufacturers claimed that their sealer would deal with hairline cracks in masonry. One of these sealers had been tested by WES. The manufacturer of the other sealer stated that he would inspect the walls of the Commissary building and participate in the field test. The manufacturer did not visit Fort Leonard Wood or report back to WES; therefore, only the sealer that had been tested by WES was used in the field test.

On 10 May 93, a representative from the supplier of the sealer visited Fort Leonard Wood and brought 2 gal of the sealer and a spray applicator. Because of the rain that day, the sealer could not be applied to the test section of the wall. The manufacturer recommends a drying time of at least 24 hr after a rain before the sealer is applied. The representative instructed personnel from WES how to apply the sealer by a demonstration within the loading dock, which was protected from the rain by an overhang. Application of the sealer is shown in Figure 10.

The following afternoon WES personnel applied the sealer to a section of the wall that measured 9 ft high by 10 ft long. The sealer was applied by spraying at the top so that it would run down the wall, thus keeping the flow at least 4 in. below the spray. A total of 0.8 gal was applied to the test section for a coverage rate of 115 ft^2/gal. The test section started at the construction joint left of the fourth downspout from the southwest corner and proceeded west for the 10 ft. The area coated is shown in Figure 11. The sealer did slightly darken the surface of the brick which can be seen in the photograph.

4 Water-Penetration Test Results

CTL Test Results

The report of test results from CTL is in Appendix B. A total of 25 tests were performed by CTL. The anchors were left in the wall from the first set of tests so that additional tests could be made in the same area after the sealer had been applied. Three locations designated as locations 3, 4, and 5 were tested before and after application of the sealer. Tests were performed on wall areas that were tuckpointed, treated with a sealer, and as constructed. As previously stated, a test pressure of 5 psi was used for all tests.

A total of nine tests were performed on the wall area treated with the sealer, three before the sealer was applied, and six after. The sealer reduced water penetration based on tests made at the three locations that were tested before and after application of the sealer. The sealer did not completely seal the crack at the joint and mortar interface in location no. 4, as indicated by a flow rate of 20 mL/min, compared to a flow rate of >40 mL/min before the sealer was applied. Test no. 13 was made at an intersection of two joints where there was a noticeable crack. A flow rate of 1.5 mL/min was obtained at this location, which is much lower than the 40 mL/min that was obtained for other locations where cracks were observed. Since tests were not performed in this location before the sealer was applied, it would be difficult to confirm actual water reduction. The other two tests at joints showed low water penetration. Tests results indicate that the sealer did improve the resistance of the wall to water penetration. There was evidence from the test that all debonded joints could not be completely sealed by applying this sealer to the wall.

Tuckpointing did not improve the water resistance based on the three tests that were performed in this area. Test results ranged from 12 to >40 mL/min. Observations indicated water to be running into the new mortar and along the joint, which indicated that the mortar used for tuckpointing was more permeable than the original mortar.

Six tests were performed on the wall panel to the right of the area that was sealed. One of the tests was performed on the face of a brick that was

cracked. A high flow rate (>40 mL/min) was obtained indicating a deep opening in the crack. This could be another source for water entry into the wall. One test was performed at the intersection of two joints, where debonding appeared, and a flow rate of 40 mL/min was obtained. The other test locations on joints did not have excessive water penetration; however, no cracks were observed at these locations.

CTL's water penetration tests did indicate that large amounts of water could enter the wall through debonding of mortar joints. High flow rates were obtained for nearly every joint tested that had a noticeable crack. The sealer appeared to reduce water penetration as demonstrated by the three tests made on the same locations before and after sealing. Tuckpointing did not improve the watertightness of the wall based on these tests. CTL's test is an accelerated test because of the 5-psi pressure, which is a much higher pressure than would occur with natural rainfall.

RILEM Tube Test Results

The RILEM tube test results are given in Table 1. The results are reported as water absorption after 5 min of testing. A total of 25 tests were performed on the Commissary building wall. Most of the tests were made over joints that appeared to be debonded. WES did not test any of the wall sections before tuckpointing or sealing. Two locations tested earlier by CTL, locations no. 4 and no. 5, were retested using the RILEM tubes. WES test results correlated well with CTL's results in that a water absorption of 2.7 mL was found for CTL location no. 4, and a water absorption of 0.0 ml was found for location no. 5. High test results ranging from 2.7- to >5-mL water absorption were obtained for 4 locations tested on the sealed section of the wall. Two of the test values were >5 mL, which indicates a large opening at the joint. Seven locations along the joints had very low test values ranging from 0.00 to 0.05 mL. These low results would indicate that the sealer did help in reducing water penetration.

Eight locations along joints were tested on the untreated wall section. Five of these locations had high water absorption values ranging from 1.8 to >5 mL. The other three locations were not excessively high for mortar, ranging from 0.2 to 0.5 mL. The average of these water absorption values were 0.4 mL compared to 0.01 mL for the sealed area. Based on laboratory testing, this would be about what one would expect from masonry mortar that was tested before and after application of a sealer.

Three locations along bed joints were tested on the wall section that was tuckpointed. Water absorption values ranging from 0.7 to 1.1 mL were obtained. These test values are lower than what would be expected for an unbonded joint, but they were slightly higher than the lower test values obtained on the untreated wall section. The mortar used for tuckpointing was apparently more permeable than the original mortar.

5 Literature Survey

Efflorescence

Efflorescence is a deposit of water-soluble salts left on the surface of masonry as the water evaporates. Three conditions must exist before efflorescence will occur: (1) there must be water-soluble salts present in the masonry units or mortar, (2) there must be sufficient moisture in the wall to put the salts into solution, and (3) there must be a path for the solution to migrate through to the surface where the moisture can evaporate leaving the dissolved material as a precipitate. Although unattractive, efflorescence is generally harmless. However, soluble salts can accumulate beneath a masonry surface within the pores of the material causing expansion that may spall the surface. One author (London 1988) refers to this condition as subflorescence, and another, Portland Cement Association (PCA) (1991) refers it as cryptoflorescence.

In the literature surveyed (BIA 1985a; Panarese, Kosmatka, Randall 1991; NCMA-TEK 1977; and Merrigan 1966), the most common efflorescence-producing salts were reported to be sulfates of sodium, potassium, magnesium, calcium, and iron; carbonates of sodium, potassium, and calcium. Certain vanadium and molybdenum and manganese salts found in bricks can produce a green or brown stain on the bricks. Merrigan (1966) reported that chemical analysis of efflorescent salts in Southern California revealed that they are principally sodium and potassium sulfates. These two salts are highly soluble in water after they have been deposited on the face of a wall; therefore, their removal is easily accomplished by cleaning with water. Calcium carbonates present as efflorescence are usually formed by soluble calcium hydroxide which reacts with carbon dioxide from the atmosphere. This substance cannot be normally removed with water once it has hardened. The efflorescence found on clay bricks in most cases comes from the mortar or concrete masonry backup material (Grogan and Conway 1985) Fired clay products contained less soluble material than concrete products or masonry mortar (BIA 1985a). There is a disagreement among authors (BIA 1985a; Robinson 1991; and Beall 1993) as to whether lime contributes to efflorescence. Beall (1993) reports that hydrated limes are relatively pure and generally have 4 to 10 times less efflorescing potential than cements.

Efflorescence is affected by temperature, humidity, and wind. In the summer, even after long rainy periods, moisture evaporates so rapidly that comparatively small amounts of salts are brought to the surface. Efflorescence is more common in the winter months when there is a slower rate of evaporation. Some salts such as calcium hydroxide are more soluble in cold weather.

Control of Efflorescence in New Construction

To eliminate or reduce efflorescence in new construction, it is necessary to minimize the amounts of soluble salts present in the masonry materials, water present in the masonry assembly, as well as passage of moisture through the masonry. The PCA and the Brick Institute of America (Panarese, Kosmatka, Randall 1991; BIA 1985b) recommend the following steps to prevent or control efflorescence:

Eliminating the Soluble Salts

1. Use washed sand that meets the requirement of ASTM C 33 (ASTM 1992b) for concrete and ASTM C 144 (ASTM 1992c) for mortar.

2. Use low-alkali cement.

3. Use dehydrated lime free from calcium sulfate when using lime for mortar.

4. Use a clean mixing water. Do not use salt water.

5. Never use masonry units known to effloresce while stockpiled. Use brick passing efflorescence tests in ASTM C 67 (ASTM 1992d).

6. Be certain the mixer, mortar box, mortarboards, and tools are not contaminated or corroded.

7. Consider using autoclaved concrete masonry units.

8. Materials should be stored in such a manner as to avoid their saturation by rain, snow, and ground moisture, as well as contamination from salts.

There are no published test procedures for determining the efflorescence potential of masonry mortars or concrete masonry units. This makes it difficult in the selection of concrete materials that have a low potential for efflorescence. All literature reviewed by WES that commented on the types of cement used for masonry mortar stated that a high-alkali cement should not be used but did not recommend any particular type. Most of the consultants and professional organizations contacted by WES also agreed that a high-alkali cement should not be used. A few did state that they were not that concerned about using high-alkali cements because of the type of soluble salts (potassium

and sodium sulfates) associated with the cement. These two salts are highly soluble in water and can easily be removed.

Eliminating Moisture and Water Penetration into Masonry

1. Prevent inadequate hydration of cementitious materials caused by cold temperatures, premature drying, or improper use of admixtures; provide specified curing.

2. Prevent entry of water by giving proper attention to design details for correct installation of waterstops, flashing, and copings.

3. During construction, all walls should be kept dry by covering with a waterproof membrane at the end of each day's work or when rain is expected.

4. Install vapor barriers in exterior walls or apply coating to interior surfaces which will minimize condensation within masonry.

5. Apply paint or other proven protective treatments to the outside surfaces of porous masonry walls.

6. Tool all mortar joints with a V- or concave-shaped jointer to compact the mortar at the exposed surface and create a tight bond between the mortar and masonry units.

7. Carefully plan the installation of lawn sprinklers or another water source so that walls are not subjected to unnecessary wetting.

8. If architecturally feasible, use wide overhanging roofs to protect walls from rainfall.

9. Design for pressure equalization between the outside and the void within the masonry wall.

Workmanship affects water permeance of masonry walls more than any other factor. The points on the wall-face most accessible to the entrance of water are at junctures of brick and mortar (Beall 1993). Unbonded mortar joints and unfilled mortar joints, like those found on the southside of the Commissary building, would cause excessive water penetration into the wall. Grimm (1982) and Beall (1993) reported that the extent of bond between brick and mortar and full mortar joints is critical to water permeance. Mortar having high water retentivity should be used with highly absorptive brick during hot, dry weather. Mortar having low water retentivity should be used with low absorptive brick during cold weather. Very little information was found on the effects that different mortar mixtures have on bond loss to clay bricks. Some of the consultants contacted stated that high-strength mortars, such as that used for the Commissary building, would more likely separate from the brick on hot days than lower-strength mortars containing higher amounts of lime. One stated that higher bond strengths would be obtained for

mortars having higher cement contents, but the total area bonded may be less. Beall (1993) reported that mortars with too much cement and too little lime are stiff and do not readily penetrate porous unit surfaces, and that stronger mortars that have high cement content can show substantial shrinkage when exposed to alternate wetting and drying conditions.

Removal of Efflorescence

Efflorescence is relatively easy to remove compared to other stains. Many efflorescing salts are water soluble, and many will disappear with normal weathering. Efflorescence should be removed in warm, dry weather, since removal in cold, wet weather may bring more salts to the surface. To minimize the effects of cleaning an effloresced masonry wall, always begin with the gentlest method possible and progress toward harsher methods as needed. Robinson (1991) stated that the worst efflorescence problems can develop from the cleaning procedure used on the masonry. Chemical cleaning methods can create soluble salts. For new construction, he recommended that the mason clean the brickwork with a burlap sack as the work progress and to wash the morning's brickwork with water in the afternoon and the afternoon's brickwork the next morning. One author (Hurd 1992) suggested that trials be made first before deciding on a cleaning method, beginning with the gentlest method and working to the harsher methods. One suggested sequence of test approaches for removal of efflorescence is:

1. Dry scrubbing with a stiff fiber brush.

2. Wetting down the surface, scrubbing with a stiff fiber brush, followed by low-pressure water.

3. Steam cleaning or high-pressure washing.

4. Chemical cleaning compounds.

5. Abrasive blasting, either wet or dry.

Dilute acids (muriatic, phosphoric, and acetic) are normally the chemicals selected when removing efflorescence with chemicals. A very dilute acid (1 part muriatic acid to 19 parts water) should be tried first before stronger acid solutions are used. Listed below are dilutions that may be used:

- 1 part muriatic acid in 9 to 19 parts water
- 1 part phosphoric acid in 9 parts water
- 1 part phosphoric and 1 part acetic acids in 19 parts water

For the removal of efflorescence that is deep into the masonry, the use of a poultice has been recommended (London 1988; Ashurst 1988). A poultice is a paste made with a solvent or reagent and an inert material. It works by dissolving the efflorescence and leaching or pulling the solution into the poultice. The inert material may be fuller's earth, diatomaceous earth,

bentonite, or a paper pulp. The wall is saturated for several days by spraying with water until wetting has occurred for a considerable depth. When the wetting process is complete, the absorbent inert material is made into a paste with water. The poultice is then plastered onto the wet wall. As the poultice dries out, it draws salt-laden water from the masonry.

Methods for Reducing or Eliminating Efflorescence from Recurring

A number of contacts were made by phone with consultants and professional organizations to discuss the efflorescence problem at Fort Leonard Wood. It should be noted that some of these people were contacted before field test were completed. All parties agreed that the water penetration into the walls must be reduced significantly to stop efflorescence from recurring. The methods to accomplish this varied with different sources contacted, which would be expected since none had actually inspected the buildings. Two of those contacted strongly agreed that tuckpointing was the only solution. One suggested that a sealer be applied to the walls. Others stated that a sealer would be effective if the sealer would stop the passage of water into the wall and that the sealer would let water vapor pass through the wall. A few were strongly against the use of any sealer.

Most of the literature reviewed by WES (BIA 1985b; NCMA-TEK 1977), dealing with surface coatings for masonry, recommended that a coating not be applied if it could not stop the mechanisms causing the efflorescence. Water gaining entrance to the masonry would still take soluble salts in solution and then be deposited behind the surface treatment in the masonry. Hydration-dehydration reactions of the salts could then develop causing spalling of the brick. Most of the people contacted recommended the siloxane sealers rather than the acrylics and silicones.

6 Summary

Some of the buildings at Fort Leonard Wood were identified as having excessive efflorescence. Two inspections of the buildings were made to determine the reason for the efflorescence. The design details of the building appeared to be satisfactory and it was concluded that the only source for water passage was through the walls from the outside, during which salts were deposited as the water evaporated. It appeared that the water was entering through the face of the wall at debonded mortar joints. Submittals reviewed at Fort Leonard Wood indicated that a high-strength mortar was used for the Commissary building, the building having the highest degree of efflorescence. Personnel contacted by WES and literature suggest that debonding is more likely to occur when using a high-strength mortar instead of a mortar having a higher lime content, especially during hot weather. Samples of the brick and mortar were sent to the MRD Laboratory for analysis. Test results indicated that the source of the efflorescence was from the masonry mortar and not the brick.

WES arranged for field tests on the south (rear) wall of the Commissary building to determine if debonded mortar joints were the source for the water entering the wall. Two test methods, RILEM tubes and a method developed by CTL, were used for determining the water permeance of the wall. High water uptake values were obtained at many locations along the mortar joints from both test methods, indicating that there was debonding in these areas or there were voids between the brick and the mortar.

WES also arranged for tuckpointing of mortar joints and application of a surface sealer to determine if these remedial procedures would reduce water penetration into the wall. When the contractor was cutting out the old mortar joints for tuckpointing, it was discovered that there were many unfilled head joints. Unfilled joints would also contribute to excessive water entry into the wall. A reduction in water penetration was noted in the area treated with the surface sealer. The surface sealer failed to prevent water from coming through a great number of the mortar joints that were open. The mortar used for tuckpointing was more porous than the original mortar, which was disappointing. The tuckpointing did appear to close large voids caused by the debonding.

7 Conclusions and Recommendations

Conclusions

The efflorescence was calcium carbonate and the soluble salt was calcium hydroxide in the masonry mortar and not the brick. The prolonged moist-cool days and excessive water entering into the wall produced the efflorescence on the building walls.

Water permeance tests indicated that the water was entering through the walls from the exterior. Debonded mortar joints and unfilled mortar joints were the contributing factors for the passage of excessive water into the wall. Poor workmanship is the cause of the unfilled mortar joints, and it is probable that high-strength mortar may have contributed to the debonding where it was used. Poor workmanship or a combination of poor workmanship and high-strength mortar could have caused the debonding.

The concrete sealer reduced water penetration into openings caused by debonding but did not stop entry of the water. The RILEM tube tests and the tests performed by CTL were able to detect openings between the mortar and the brick and absorption of the clay brick and mortar. A test as described in ASTM E 514 (ASTM 1992e) would have been more valuable in determining the effectiveness of the sealer and tuckpointing, because a much larger area could have been tested and a percentage of water reduction determined.

The tuckpointing of the mortar joints did appear to close the opening between the mortar and brick. The mortar used for the tuckpointing was more porous than the original mortar based on the water permeance test.

Recommendations

Based on the results of field tests at Fort Leonard Wood, a sealer would not completely seal the surface and could cause damage to the brick if efflorescence continues. Tuckpointing is very expensive, and there is no guarantee that this would completely stop the efflorescence. Therefore, it is

recommended that no sealer be applied to the walls and that the joints not be tuckpointed. If there is evidence that masonry walls are being damaged because of excessive water entering into the walls, tuckpointing or the application of a surface sealer should be considered.

It is recommended that the walls be cleaned using the methods described in this report. Cleaning of the walls should not be initiated until late spring when the weather is warm. Rain may remove the efflorescence as before, with no need for cleaning.

A Type N mortar as specified by proportions in ASTM C 270 (ASTM 1992a) is recommended for all exterior above-grade applications especially for warm- or hot-weather construction. For cold-weather construction, a Type S mortar may be used. For better control of the mortar mixtures, it is recommended that premix mortar be used and that a proportion be specified. For a Type N mortar, the proportions should be 1 part portland cement, 1 part lime, and 6 parts aggregate by volume. One could also specify that the aggregate proportion of the mixture be from 5 to 6 parts by volume to obtain the best workable and water-retentive mixture.

The Corps of Engineers Area Office at Fort Leonard Wood should monitor the performance of the two test areas on the south side of the Commissary building for at least 2 years to determine if the tuckpointing and surface sealer are preventing efflorescence from recurring. Any damage to the clay brick or mortar joints in these two areas should also be noted.

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b. Designation C 33, "Specification for concrete aggregates."

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d. Designation C 67, "Method of sampling and testing brick and structural clay tile."

e. Designation E 514, "Test method for water permeance of masonry."

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Table 1
RILEM Tube Test Results

No.	Location	Water absorption mL/5 min
1	Sealed area, No. 4 test area CTL	2.7
2	Sealed area, No. 5 test area CTL	0.0
3	Sealed area, face of brick	0.0
4	Sealed area, head joint	0.00
5	Sealed area, bed joint	0.05
6	Sealed area, bed joint	0.0
7	Sealed area, head joint	1.4
8	Sealed area, bed joint (large opening)	> 5.0
9	Sealed area, intersection of two joints	> 5.0
10	Sealed area, bed joint	0.0
11	Sealed area, bed joint	3.0
12	Sealed area, bed joint	0.0
13	Untreated area, bed joint	1.8
14	Untreated area, head joint	0.4
15	Untreated area, bed joint	2.8
16	Untreated area, head joint (large opening)	> 5.0
17	Untreated area, bed joint	0.5
18	Untreated area, intersection of two joints	0.2
19	Untreated area, bed joint	3.0
20	Untreated area, bed joint	2.8
21	Untreated area, face of brick (crack)	> 5.0
22	Untreated area, face of brick (crack)	1.4
23	Tuckpointed area, bed joint	1.0
24	Tuckpointed area, bed joint	0.7
25	Tuckpointed area, bed joint	1.1

Appendix A
WES Research Proposal

Revised 19 Feb 93

RESEARCH PROPOSAL

Title: Removal and Prevention of Efflorescence on Masonry Structures

Problem: Efflorescence is a deposit, usually white in color, that may deposit on the surface of masonry. For efflorescence to occur, there must be: (a) soluble salts in the masonry materials; (b) moisture to dissolve the soluble salts; and (c) evaporation or hydrostatic pressure to move the dissolved salts to the surface. Many of the Corps of Engineers's masonry structures have efflorescence. There is very little guidance available for Corps personnel in how to prevent or reduce efflorescence in new construction. There is also very little guidance on what can be done to eliminate or reduce efflorescence in existing structures.

Objective: To determine the most effective ways to remove efflorescence from existing buildings and to prevent efflorescence from recurring. Develop guidance for the Corps of Engineers in new construction for reducing or eliminating efflorescence.

Description of Work: The research will be divided into two phases. The first phase will be to investigate the best procedures for removing efflorescence on existing buildings and methods for reducing or eliminating the efflorescence from recurring. The second phase will be to provide guidance on how to reduce or eliminate efflorescence on new construction.

Phase I:

(1) Make field visits to observe efflorescence at Fort Leonard Wood and obtain data and information on construction practices to determine reason for efflorescence. Determine through inquiries and literature research possible answers to what can be done to eliminate/reduce efflorescence in existing structures and what can be done to construction specifications or practices to prevent/reduce efflorescence in new construction. Possible sources for information include:

(a) ACI Committee on Masonry

(b) National Concrete Masonry Association

(c) Brick Institute of America

(d) ASTM

(e) Consultants in the field

(2) Work with the Kansas City District on the existing efflorescence problem at Fort Leonard Wood, Missouri. Information obtained from the survey will be for the selection of

of cleaning methods and recommendations for treatments or corrective methods to eliminate/ reduce the efflorescence on the existing buildings. The Commissionary building at Fort Leonard Wood would be used for field testing of cleaning methods, tuckpointing of joints, and other treatments such as penetrating sealers. Construction Technology Laboratory (CTL) will be conducted about testing some of the walls for water permeation using an apparatus designed by their organization before field tests are performed. These tests should conclude whether the moisture penetration into the walls is due to unbonded joints or permeability of the masonry materials. A wing wall and the backside of the Commissary building, both having efflorescence, would be used as the field test sections. CTL will then determine the water permeation after the field test sections have been completed.

(3) A report on the Phase I work will be prepared, which will include the findings from the survey, and the results of the field test.

MILESTONES: Listed below are the milestones for Phase I:

Title	Schedule from Time of Start (2/93)
Information survey	1 month
Field tests at Fort Leonard Wood	2 months
Report for Phase I	1 month
Completion 9/6	4 months

Phase II:

(1) Test wall panels will be constructed at the U.S. Army Engineer Waterways Experiment Station (WES) using masonry materials obtains from suppliers at Fort Leonard Wood to simulate the problem so that corrective procedures can be evaluated. If feasible, an inconspicuous area, such as a wing wall, on the new Physical Fitness Center at Fort Leonard Wood would be used to evaluate different masonry mixtures for efflorescence potential.

(2) Details for Phase II of the research project will be submitted at a later date.

Appendix B
CTL Test Report

CTL Structural/Architectural Engineering, Consulting, & Materials Technology
5420 Old Orchard Road, Skokie, Illinois 60077-1030
708/965-7500 800/522-2CTL Fax: 708/965-6541

July 14, 1993

Mr. Tony Husbands
Waterways Experiment Station
U. S. Corps of Engineers
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Fax: (601) 634-4238

Accelerated Field Water Penetration Testing on Masonry Walls
Building 485, Fort Leonardwood, MO

Dear Mr. Husbands:

As authorized Construction Technology Laboratories, Inc. (CTL) has performed several accelerated field water penetration tests on masonry surfaces at the southwest wall of Building 485, Fort Leonardwood, MO.

The wall surface consists of a brick veneer with vertical expansion joints at approximately 40-ft centers. Reportedly, water leakage has resulted in efflorescence on the surface of the wall.

CTL's objective was to perform accelerated field water penetration tests at various locations throughout the wall. CTL's field work was performed by Mr. Russ Hall on two separate field trips. The first field trip was made on May 11, 1993. During this trip seven (7) accelerated field water penetration tests were performed on mortar joints and brick faces prior to any remedial work. During our second field trip, performed in June, 1993, additional tests were performed on wall areas that were tuckpointed, treated with a sealer, or untreated. Some tests were performed at the same locations as tests performed during our first field trip.

The tests were performed using the accelerated field water penetration apparatus developed at CTL.

The location of all tests are reflected on Figure 1. Table 1 reflects the test results. The results indicate the following:

1. The resistance of masonry joints before tuckpointing or the application of a sealer ranged from adequate to unacceptable. Water penetration flow rates varied from 0.01 to over 40 ml/min. (40 ml/min is the maximum readout on the apparatus).

2. Areas where a sealer was applied exhibited an appreciable improvement in the resistance of the joints to water penetration. This is demonstrated by tests performed at locations 3, 4, and 5 before and after the application of the sealer.

3. Tuckpointed areas do not appear to exhibit an appreciable improvement in the resistance of the joints to water penetration.

CTL

Mr. Tony Husbands
July 14, 1993
Page 2

4. The two tests performed on the front entrance mockup exhibit unacceptable rates of water penetration.

We hope that the above information is sufficient for your present needs. If you have any questions, please call.

Sincerely yours,

Kami Farahmandpour
Evaluation Engineer

Copy to--

H.C. Kosel
G.R. Hall
260471
050504

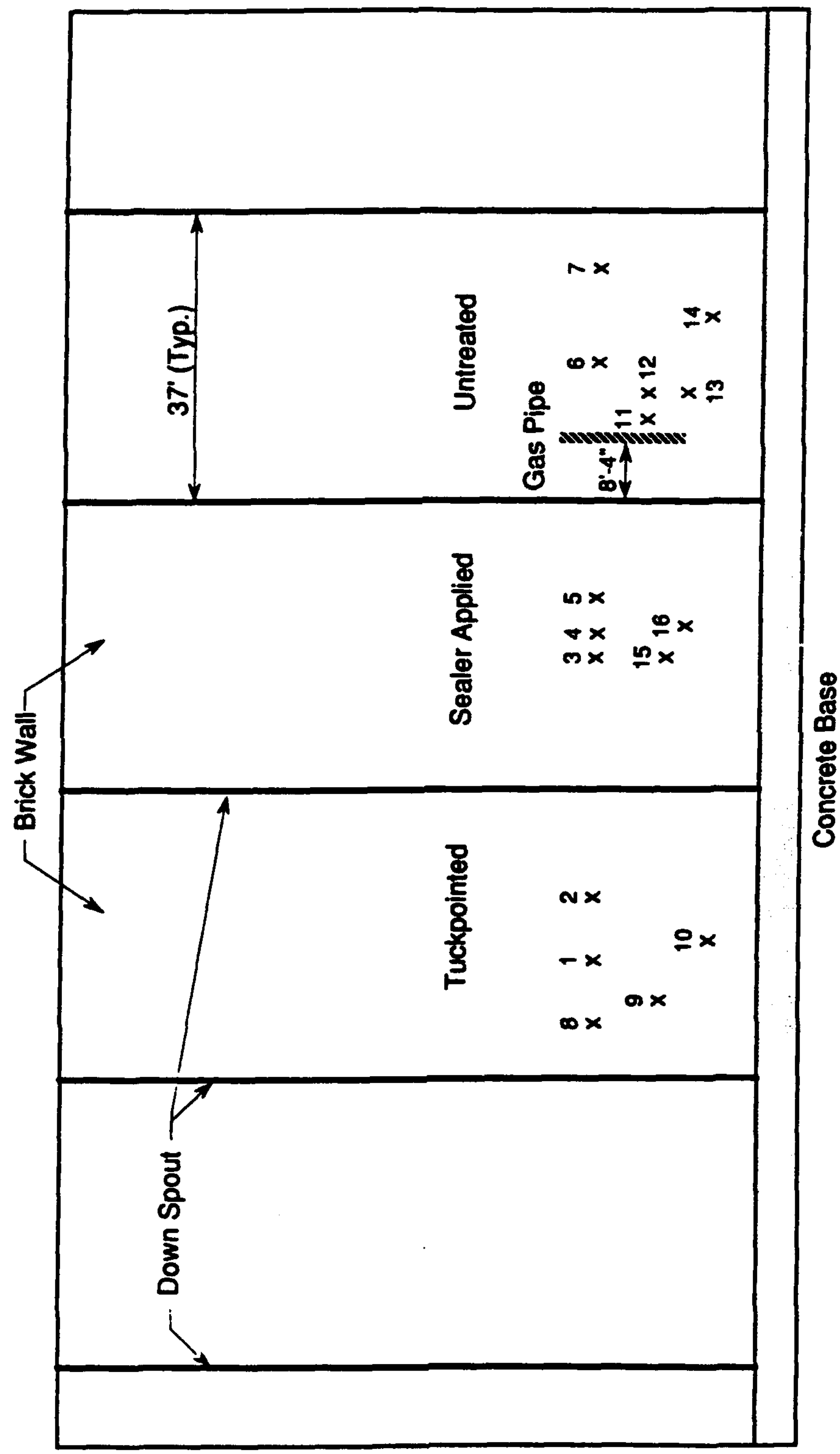

FIGURE 1 TEST LOCATIONS

TABLE 1 - ACCELERATED FIELD WATER PENETRATION TEST RESULTS

TEST NO.	LOCATION NO.	TEST PRESSURE (psi)	FLOW-RATE (ml/min)	SURFACE CONDITION	COMMENTS
1	1	5	0	Untreated	Test performed on brick face
2	2	5	1.5	Untreated	Test performed at intersection of two joints
3	3	5	2.0	Untreated	Test performed on brick face
4	3	5	1.5	Sealer applied	Test performed on brick face
5	4	5	40+	Untreated	Test performed at intersection of two joints
6	4	5	20.0	Sealer applied	Test performed at intersection of two joints
7	5	5	1.0	Untreated	Test performed on bed joint
8	5	5	0	Sealer applied	Test performed on bed joint
9	6	5	0.2	Untreated	Test performed at intersection of two joints
10	7	5	40+	Untreated	Test performed at intersection of two joints, crack observed in the joint
11	8	5	40+	Tuckpointed	Test performed on bed joint
12	9	5	12.0	Tuckpointed	Test performed on bed joint

TABLE 1 - ACCELERATED FIELD WATER PENETRATION TEST RESULTS

TEST NO.	LOCATION NO.	TEST PRESSURE (psi)	FLOW-RATE (ml/min)	SURFACE CONDITION	COMMENTS
13	10	5	40+	Tuckpointed	Test performed at intersection of two joints
14	11	5	0.01	Untreated	Test performed on bed joint
15	12	5	0.02	Untreated	Test performed on bed joint
16	13	5	1.5	Sealer applied	Test performed at intersection of two joints, crack observed at test location
17	14	5	40+	Untreated	Test performed on brick face, crack observed at test location
18	15	5	0.02	Sealer applied	Test performed at intersection of two joints
19	16	5	0.05	Sealer applied	Test performed on bed joint
20	17	5	40+	Untreated	Test performed at front entrance mockup
21	18	5	40+	Untreated	Test performed at front entrance mockup

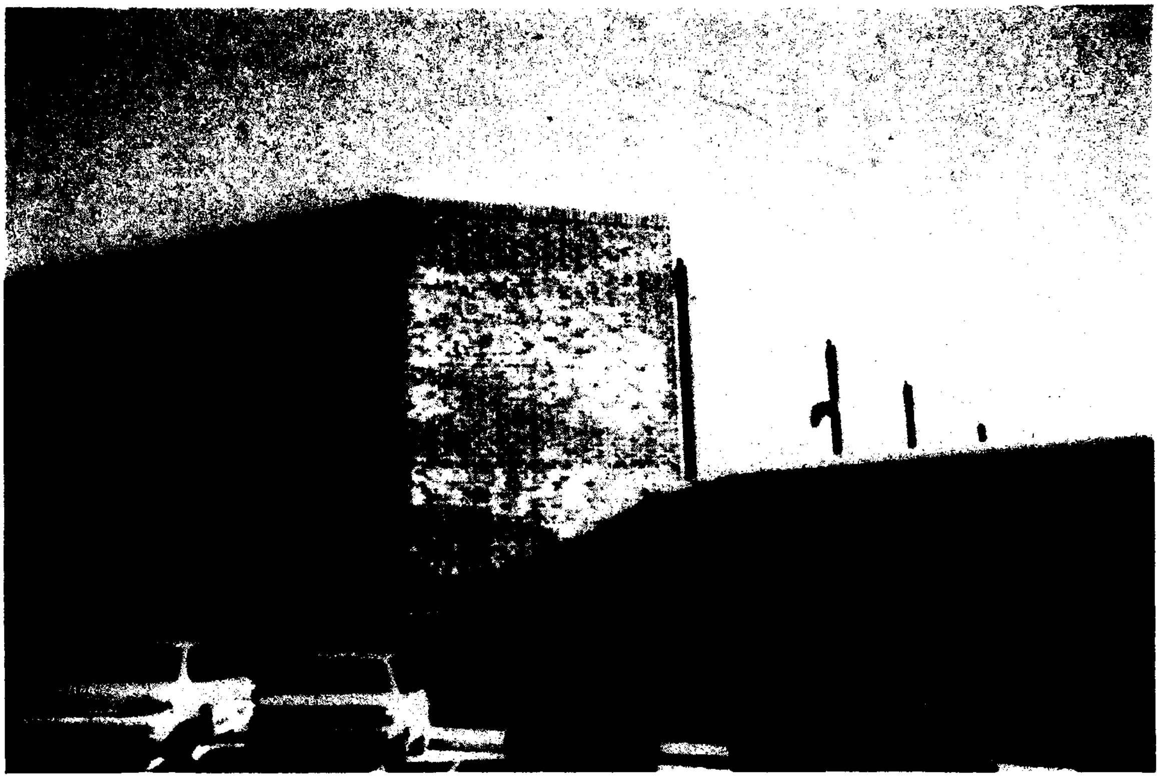

Figure 1. Effloresecence on Commissary building

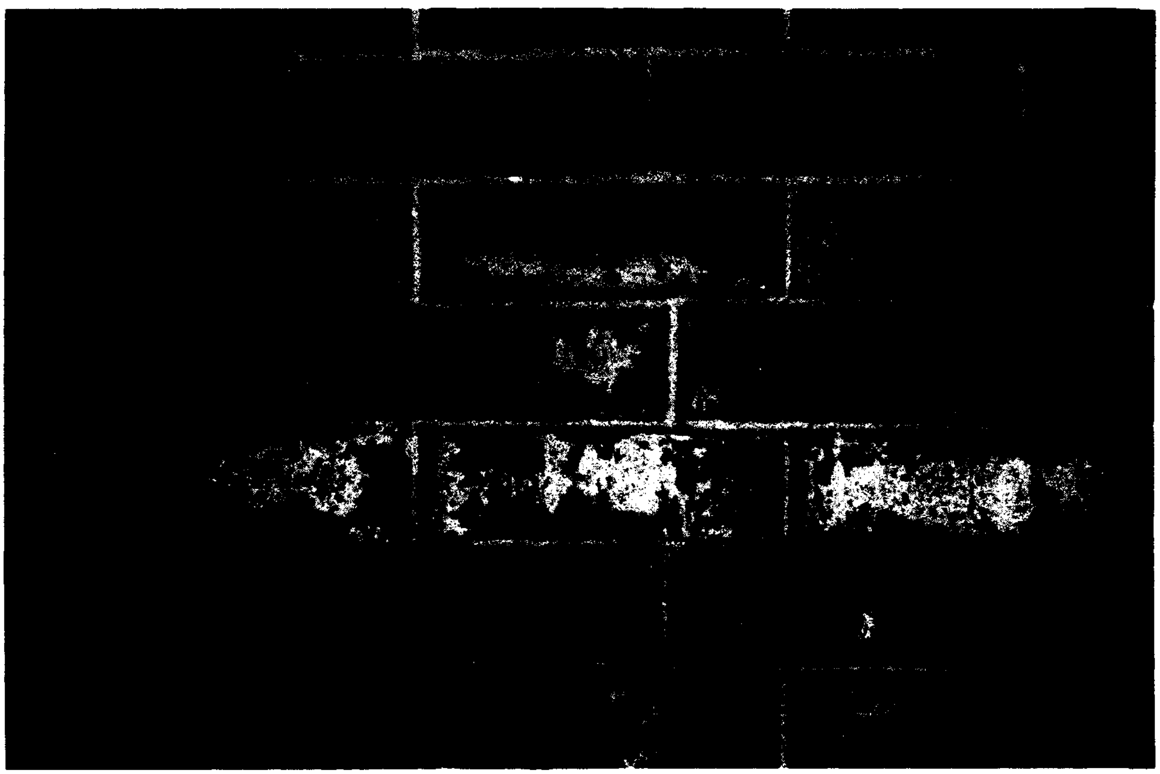

Figure 2. Close-up of efflorescence on Commissary building

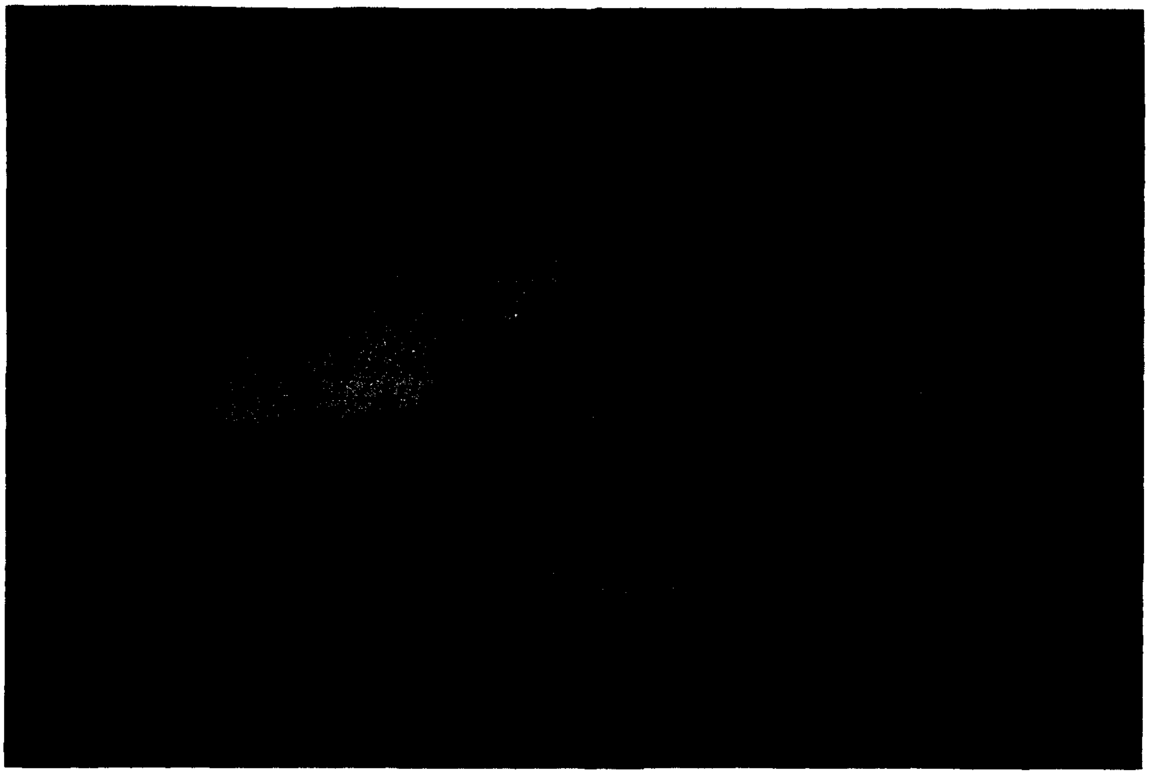

Figure 3. Engineer Center showing Library wing

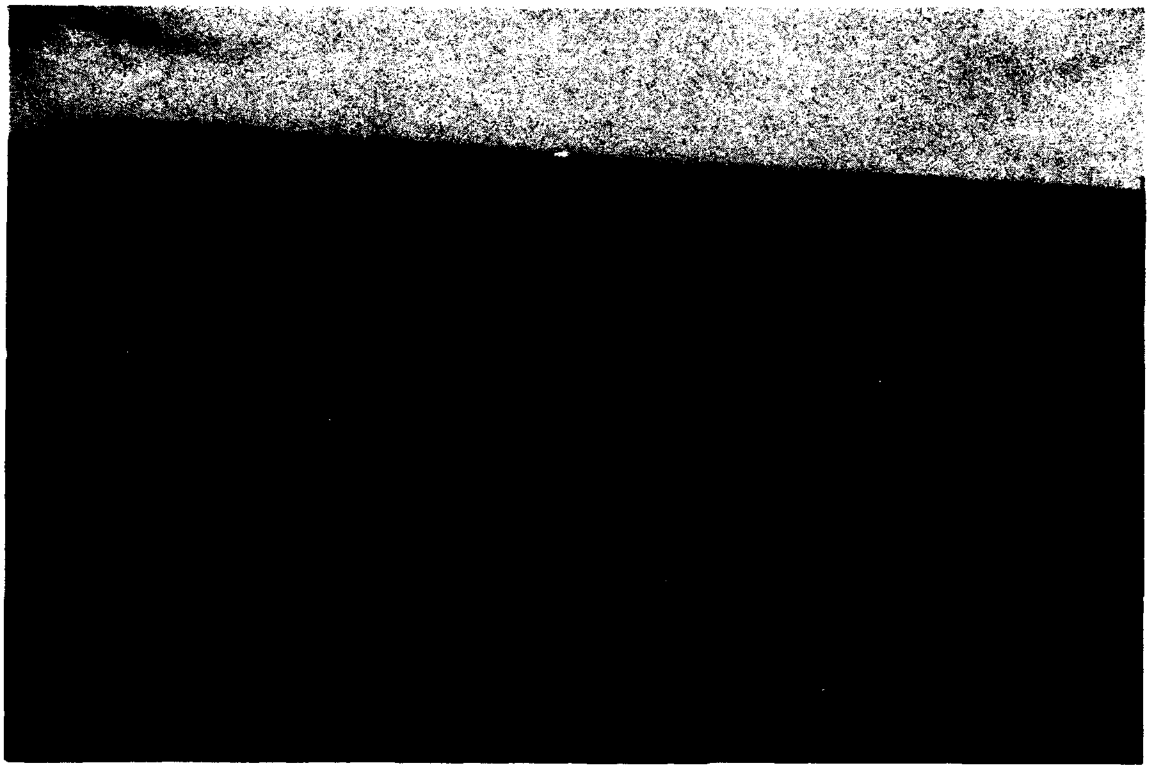

Figure 4. Southwest side of Commissary building where field tests were performed

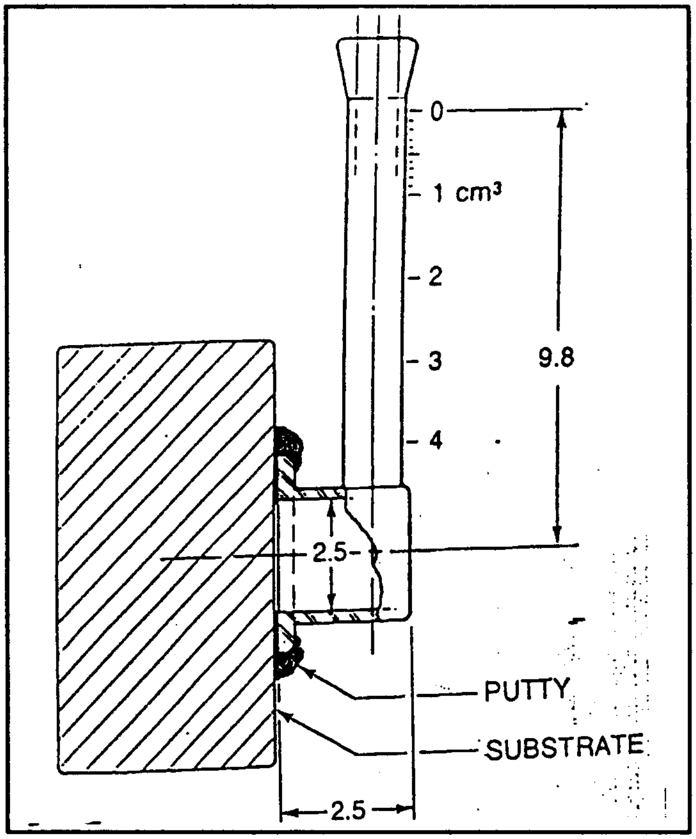

Figure 5. RILEM tube

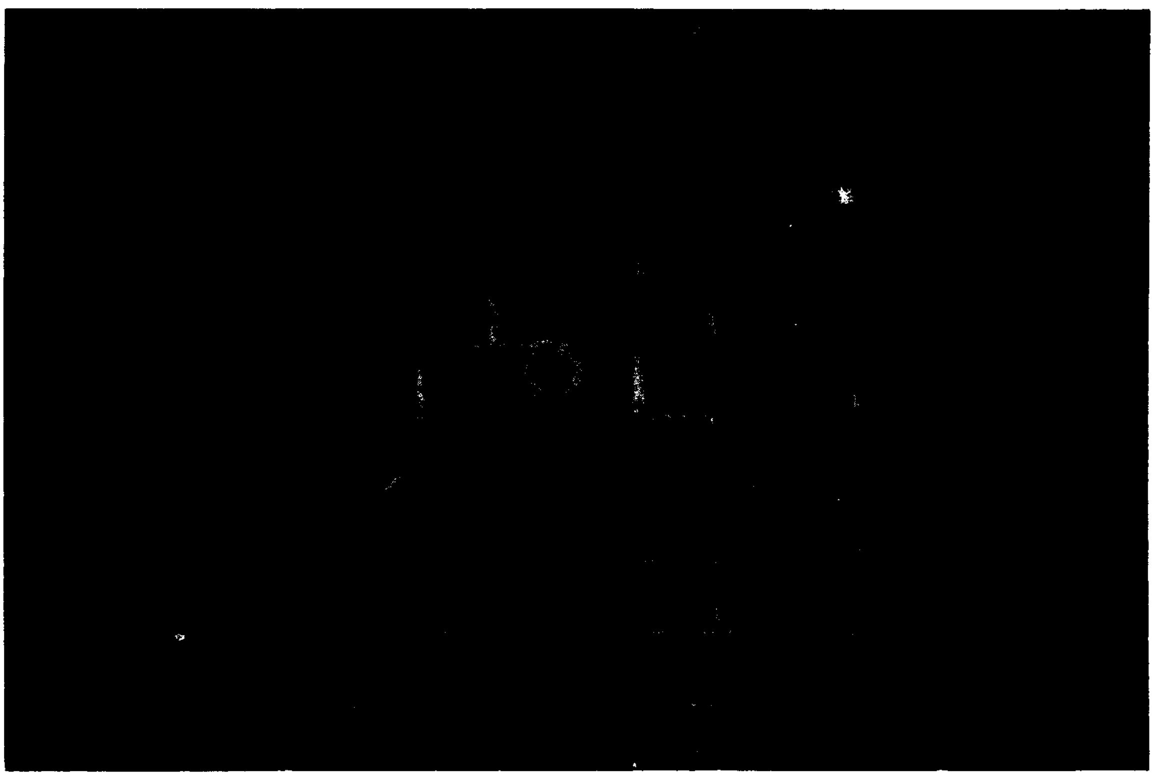

Figure 6. CTL test apparatus installed on wall

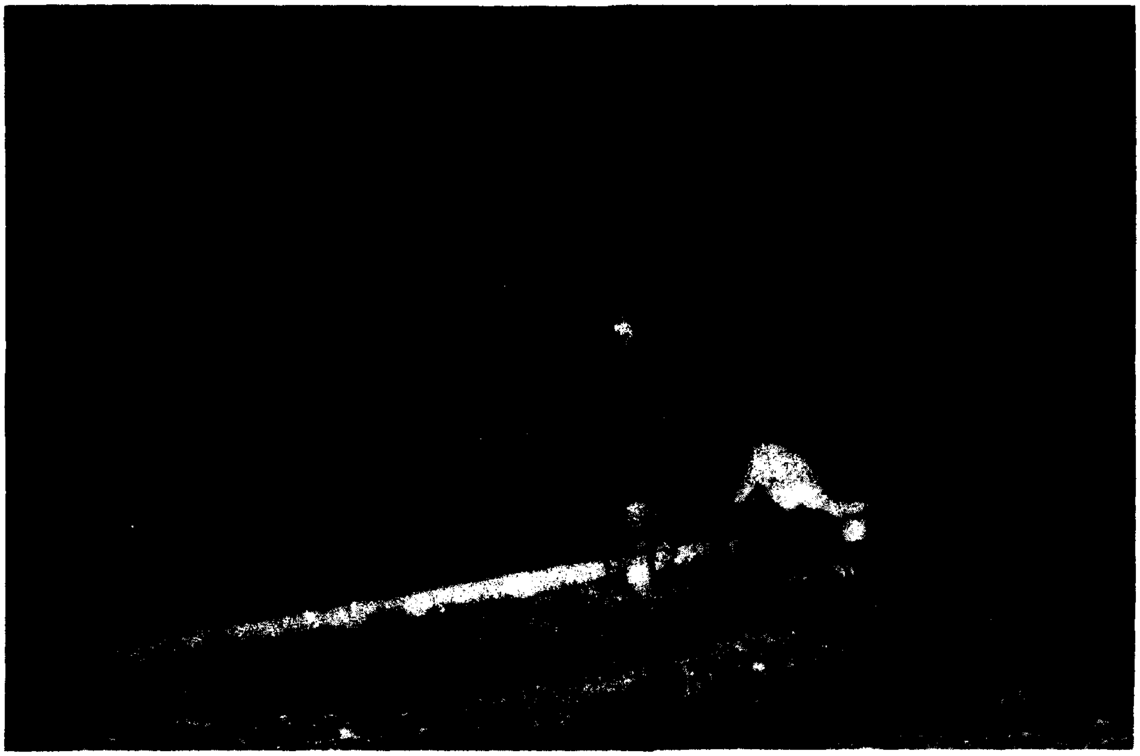

Figure 7. Testing water permeance of wall with CTL test apparatus

Figure 8. Saw cutting of mortar joints for tuckpointing

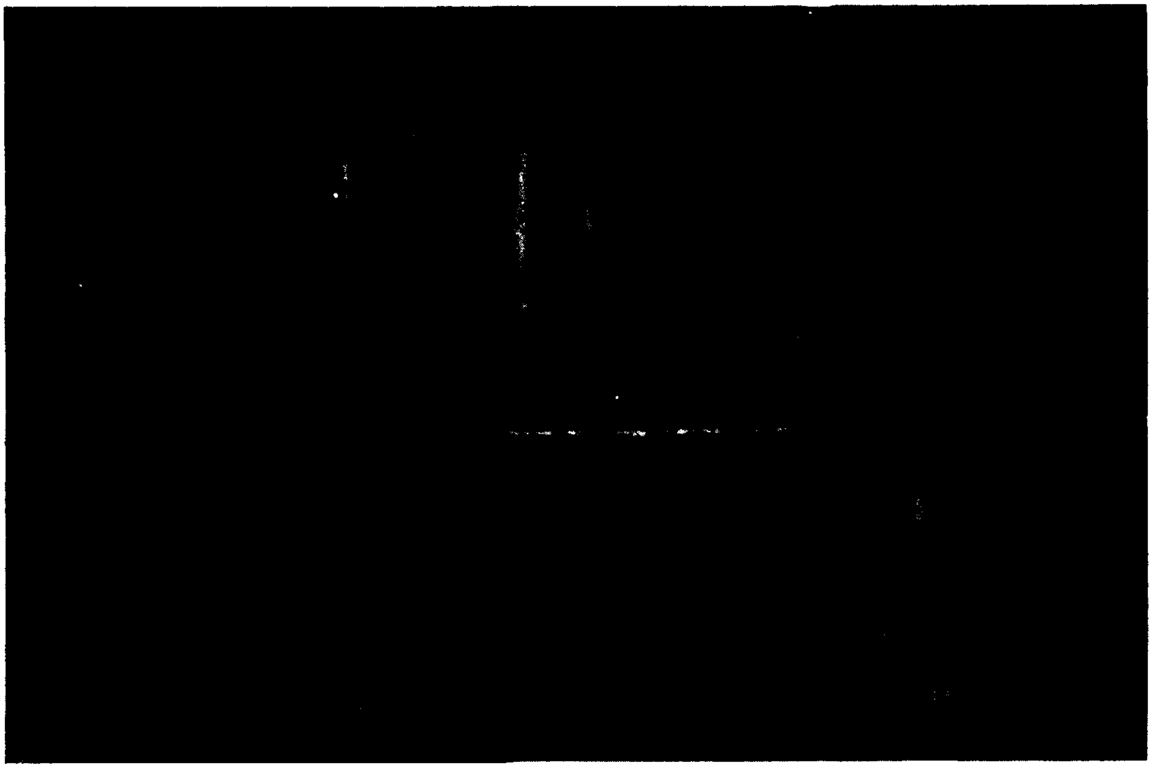

Figure 9. Unfilled mortar joints exposed after saw cutting

Figure 10. Application of sealer

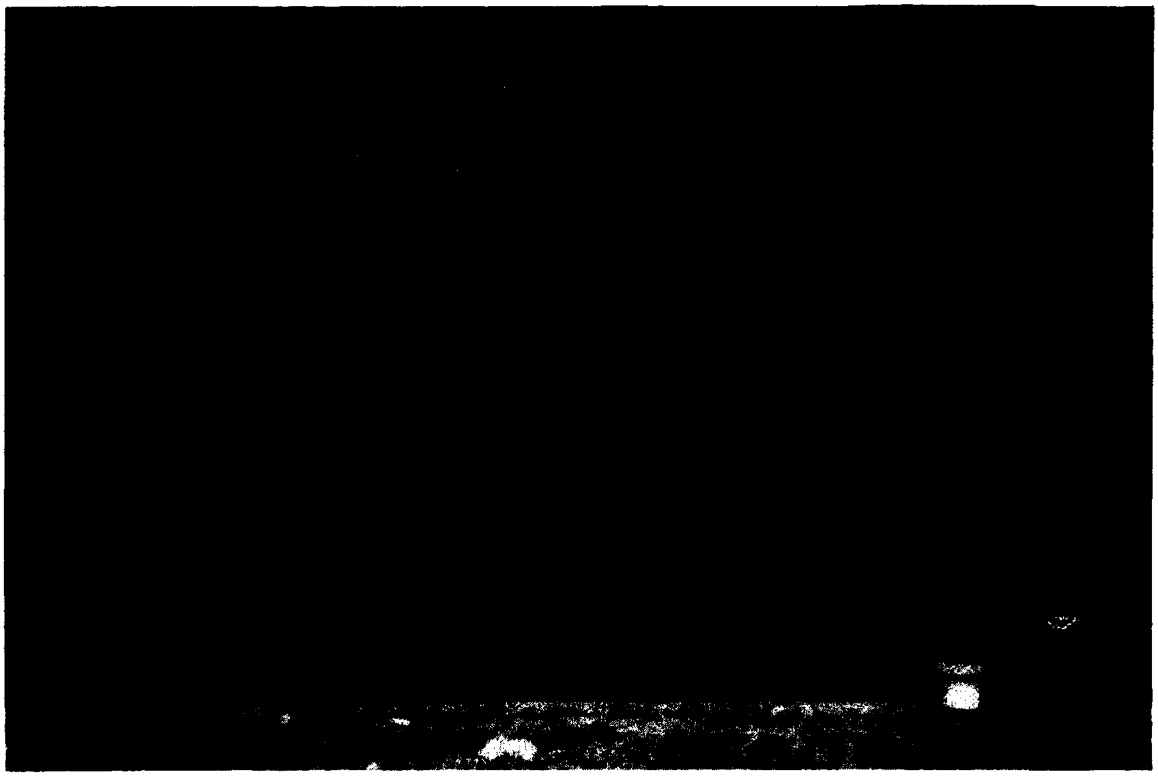

Figure 11. Test section of wall coated with sealer

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1994

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Efflorescence Study, Fort Leonard Wood, Missouri

5. FUNDING NUMBERS

6. AUTHOR(S)
Tony B. Husbands

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper SL-94-1
(CTIAC Report 91)

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Division, Missouri River, P.O. Box 103 Downtown Station, Omaha, NE 68101-0103; U.S. Army Engineer District, Kansas City, 700 Federal Building, Kansas City, MO 64106-2896

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. This report is also published as CTIAC Report No. 91.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The U.S. Army Engineer Waterways Experiment Station (WES) was asked to assist in the investigation of the efflorescence problem at Fort Leonard Wood, Missouri. An inspection of the buildings at Fort Leonard Wood was made by WES personnel on 26 January 1993. Personnel from the U.S. Army Engineer Division, Missouri River, U.S. Army Engineer District, Kansas City, and Headquarters, U.S. Army Corps of Engineers, were also present for the inspection. A Research Proposal (Appendix A) was prepared by WES, and this study was begun in February 1993. A survey was made through a literature search and contacting consultants and professional organizations to determine what could be done to eliminate or reduce efflorescence in existing structures and what could be done to construction specifications or practices to prevent/reduce efflorescence in new construction.

The Commissary building at Fort Leonard Wood was selected as the site for field testing which included: (1) tuckpointing of mortar joints, (2) application of surface sealers, and (3) water penetration tests.

14. SUBJECT TERMS

Brick	Mortar
Efflorescence	Sealers
Masonry	

15. NUMBER OF PAGES
41

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		